

Near Shore Wave and Sediment Processes

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LONG-TERM GOALS

Long-term goals are to predict the nearshore wave-induced three-dimensional velocity field and induced sediment transport over an arbitrary bottom composed of sediments ranging from mud to coarse sand given the bathymetry, bottom type and offshore wave conditions.

OBJECTIVES

The interrelationship of wave-induced hydrodynamic and sediment processes over the vertical and morphologic processes at the bed are measured and modeled. The primary mechanism for changes in momentum flux that drive nearshore hydrodynamics is due to the dissipation by breaking waves, the processes of which are poorly understood. Bottom boundary layer measurements are obtained to determine bottom stress and dissipation. Sediment transport is measured in response to the measured mean longshore and cross-shore currents, wave orbital velocities, and induced stresses. The small-scale morphology, which acts as the hydraulic roughness for the mean flows and perturbs the velocity-sediment fields, is measured as a function of time to examine cross- and alongshore variations. The range of sediment environments range from mud to coarse grain sand.

APPROACH

We participated in the first comprehensive experiment to measure wave transformation over muddy bottoms at Cassina Beach, Brazil (MUDEX) with a 6-week deployment of two cross-shore arrays of wave, velocity and suspended sediment sensors. Process models for breaking waves, momentum mixing due to the interaction of alongshore and cross-shore vertical mean profiles, and bottom shear stress enhanced by the form drag of bedforms and by turbulence of wave breaking are compared with observations.

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WORK COMPLETED

We participated in the MUDEX experiment at Cassina Beach, Brazil. The experiment was conducted at the start of winter in the Southern Hemisphere to measure waves from storms over the period 24 April to 24 June 2005. The beach morphology was alongshore barred. The experimental objectives were to measure directional wave spectral transformation over heterogeneous sediments, to determine dissipation due to wave interaction with a muddy bottom, and to measure longshore currents and sediment transport. To meet these objectives, waves and velocities were measured by two cross-shore arrays, one transect within the muddy region offshore and a second, simplified transect over the homogeneous sandy beach nearer to shore and outside the muddy region. The first surf zone array consisted of an offshore autonomous pressure sensor plus four PUVs along with an instrumented tower that measured pressure, horizontal currents and turbidities over the water column. These instruments were located shoreward of an offshore wave array so that wave transformation was tracked from deep water through the surf zone. The second array was composed of four autonomous pressure sensors.

Work completed includes analysis of rip currents and their modeling for the RIPEX and NCEX experiments. A series of papers on the dynamics of rip currents were completed and are listed in the bibliography.

RESULTS

A focus of our research has been to measure and predict rip current generation. We have conducted two field experiments measuring rip currents. The analysis and modeling of rip currents during the RIPEX and NCEX experiments are described in a series of papers described in the following and summarized in a review paper on rip currents by MacMahan, et. al. (2005).

Field observations document the hydrodynamics of a morphologically-controlled rip currents utilizing a coherent cross- and alongshore arrays of co-located pressure and velocity sensors. During RIPEX conducted at Sand City, California, the beach morphology was low-tide terrace incised with quasi-periodic rip channels spaced $O(125\text{ m})$, representative of transverse bars. The relatively close spacing resulted in interaction between adjacent rip currents. By contrast, during the NCEX experiment at Torrey Pines, California, the morphology was a near planar beach with migrating rip currents creating subtle rip channel depressions $O(1:300\text{ slope})$ and separated rip current systems. The rip current observations at the two dissimilar beaches both showed the maximum rip current inside the surf zone with the rip current velocities decreasing rapidly offshore. The rip current velocities at mid-depth were negligible less than one surf zone width offshore. The rip currents are tidally modulated with the strongest velocities at low tide.

The result of our rip current observations and past field and laboratory experiments were synthesized in MacMahan et.al. (2005). Within the last decade, there have been a significant number of laboratory and field observations within rip current systems. An overview of rip current kinematics based on these observations and the scientific advances obtained from these efforts are synthesized. Rip current flows are partitioned into mean, infragravity, very low frequency (vorticity), and tidal contributions, and it is found that each contributes to the total. Data from the laboratory and the field suggest that the rip current increases with increasing wave energy and decreasing water depths. The maximum mean current occurs inside of the surf zone, where the maximum forcing is present owing to the dissipation of waves.

1) RIPEX Experiment Results

During the RIPEX, an inverse relationship between sediment accreting on the transverse bar and eroding in the rip channel was found. The mean velocity magnitudes within the rip channel (transverse bars) increased offshore (onshore) with decreasing tidal elevations and increased with increasing sea-swell energy. Eulerian averaged flows were predominantly shoreward on the transverse bars and seaward within the rip channel throughout the experiment, resulting in a persistent cellular circulation, except during low wave energy. The rip current spacing to the rip channel width was less than or equal to two, which suggests that the rip currents are influenced by each other and that no two-dimensional bar return flow should be present. The vertical velocity profile on the bar indicated that the flow was predominantly shoreward. The flow field within the surf zone was depth uniform, except for significant shear occurring near the surface, owing to Stokes drift. The wave-induced transport hypothesis is evaluated (MacMahan et.al., 2005a). Pulsations of the rip currents at infragravity frequencies were found to be the result of wave group forcing, and little alongshore spatial variation was found even in the presence of rip channels. Rip current pulsations at the infragravity band frequencies were found linked to the infragravity motions of the bound and free long waves (MacMahan et.al., 2004a). Significant very low frequency energy (VLF's) with periods greater than 5 minutes outside the region of zero-mode edge waves was found and shown to be attributed to directionally broad wave group forcing, resulting in large-scale eddies within the surf zone (MacMahan et. al., 2004b).

A non-linear wave model operating on the time-scale of wave groups was compared with measurements of infragravity motions during RIPEX (Reniers, et.al., 2005). The comparison considers a 20 day period during which significant changes in both the offshore wave climate and nearshore bathymetry occurred. The temporal variations in infragravity conditions during the experiment are strong, with computational results typically explaining 70 to 80 % of the observed infragravity motions within the nearshore. In contrast to the temporal variation, the alongshore spatial variation in infragravity intensity during the experiment is generally weak, even though the underlying bathymetry shows strong depth variations. This is due to the predominance of cross-shore infragravity motions, which experience only a weak coupling with the alongshore varying bathymetry.

Numerical computations are used to explain the presence of Very Low Frequency motions (VLF's), with frequencies less than 0.004 Hz, in the rip current velocity signals observed during the RIPEX field experiment (Reniers et. al., 2005b). Observations show that the VLF-motions are most intense within the surf zone and then quickly taper off in the offshore direction. By comparing computed cross-shore and alongshore VLF-intensity distributions with observations in a qualitative sense, the most important contributions to the VLF-dynamics are established. Model computations show that VLF-velocities depend on turbulent lateral mixing where lower (higher) values of eddy viscosity yield stronger (weaker) VLF-motions. Wave-current interaction dampens the VLF-motions compared with the case without wave-current interaction. In the case without wave-current interaction, qualitatively similar results to the inclusion of wave-current interaction can be obtained utilizing an increased eddy viscosity. VLF-motions at neighboring rip-channels are seen to interact in the computations, with stronger interactions for an asymmetric rip-channel configuration. Finally, the intermittent forcing by the wave-groups is essential in obtaining the correct cross-shore VLF-intensity distribution suggesting this is the predominant mechanism responsible for the generation of the VLF-motions observed during RIPEX. Computations suggest that VLF-motions can occasionally propagate offshore but are mostly confined to the surf zone consistent with the presence of surf zone eddies. A quantitative comparison

shows good correspondence between model computations and measurements, with generally increased (decreased) intensities during mean low (high) water levels.

2) *NECX Experiment Results*

During the NCEX experiment, morphologically controlled rip currents slowly migrated (12.5 m/day) to the south through our cross- and alongshore arrays of co-located pressure and velocity measurements, and were present for approximately 15 days (MacMahan et al., 2005c). This provided an opportunity to evaluate the hydrodynamics of a rip current system. Cross-shore velocity (one-hour average) profiles along the axis of the rip current are well documented for the first time in the field. The maximum mean offshore velocity was 0.5 m/s and occurred inside of the breakpoint, hypothesized to be influenced by the roller (Figure 1). The velocity decreases rapidly seaward of the breakpoint less than one fourth surf zone width in distance offshore. The rip current had a minimal affect on wave heights, as the Thornton and Guza [1983] wave transformation model (which does not include wave-current interaction) provides reasonable results for H_{rms} . The rip current increases the directional spreading and varies the wave direction, but the wave direction was not observed to converge into the current. The measured rip currents are classified as low-energy, based on the wave-current interaction, as a maximum of 26 % of wave blocking potentially occurred. Low frequency rip current pulsations are found forced by infragravity motions, similar to observations at RIPEX. Mode 2 edge waves were a dominant response of energy within the surf zone and have similar length scales as the rip current morphology. The infragravity rip current pulsations are minima in the vicinity of the rip current owing to the deeper channels, consistent with shallow water long wave theory. Very low frequency motions were not isolated to the vicinity of the rip current and increased during increases in sea-swell energy and low tides, with a maximum velocity occurring at the break point. VLFs are maxima in the vicinity of the rip current, and have cross-shore distributions with a maximum in the surf zone for the case of both rip currents and undertow. Rip current VLFs are hypothesized to be a combination of surf zone eddies forced by directionally spread random waves and rip current shear instabilities, as the energy is qualitatively consistent with results by Reniers et al. [2005]. Bathymetric non-uniformities directly outside the surf zone influence the kinematic non-uniformities within the surf zone, even with subtle surf zone bathymetric non-uniformities, owing to a rip channel slope (1:300).

During NCEX, the bottom boundary layer instruments were located within the tidally modulated surf zone for much of the experiment, and provide a large data set of BBL turbulence structure and sediment transport. A scanned acoustic altimeter and a new laser-based bed mapping system showed a dominance of flat, sheet flow conditions, although significant ripple fields associated with large local bed level changes were observed in discrete events during the observations. Sediment transport models under the typically non-linear, surf-zone bores are being evaluated in on-going analyses, and the influence of wave breaking on sediment suspension is being studied with this data set. A separate analysis is assessing bottom roughness changes based on the cm-resolution velocity profiles during the experiment using both direct stress estimates and log-layer estimates of friction velocity and effective roughness. The effective eddy viscosity of the water column within the surf zone remains an important unresolved question in nearshore models that is being addressed with this data set.

Suspended sediment flux profiles have been measured using the bottom boundary layer frame for the NCEX experiment. An analysis has been made of a 2 day period when a sustained offshore rip current developed centered on the cross-shore PUV array and bottom boundary layer frame. During this two day period there was a significant net accretion of the bar just offshore from the BBL frame. The bottom boundary layer frame (Figure 2) supported a cm vertical resolution velocity and sediment

concentration profiler and a morphology mapping X/Y altimeter. Hourly mean estimates of the mean near-bed current profile and horizontal sediment flux components from the BCDV (Figure 3) show a peak suspended sediment flux 3 cm above the bed. This rip current event is being used to compare suspended sediment flux with the local accretion rates offshore (Stanton 2004).

IMPACT/APPLICATIONS

Transient rip currents are generated by wave groups forced by directionally spread short waves resulting in very low frequency motions, slowly propagating surf zone eddies. These surf zone eddies then act to perturb the bathymetry generating initial rip channels that trap the eddies, giving a feedback to make the rip channels grow and increase the rip current strength.

TRANSITIONS

Efforts are ongoing in the transitioning of the Delft3D hydrodynamics model as an operational surf model. Testing and evaluation of the model have been completed and work to integrate the model with data fusion is being accomplished under the Beach Wizard program.

RELATED PROJECTS

Collaborative modeling and data comparisons of wave, current and morphology using Delt3D is being performed by Ad Reniers at Delft University.

Data acquired under this work is being used to test the Delft3D hydrodynamics model under the Beach Wizard program.

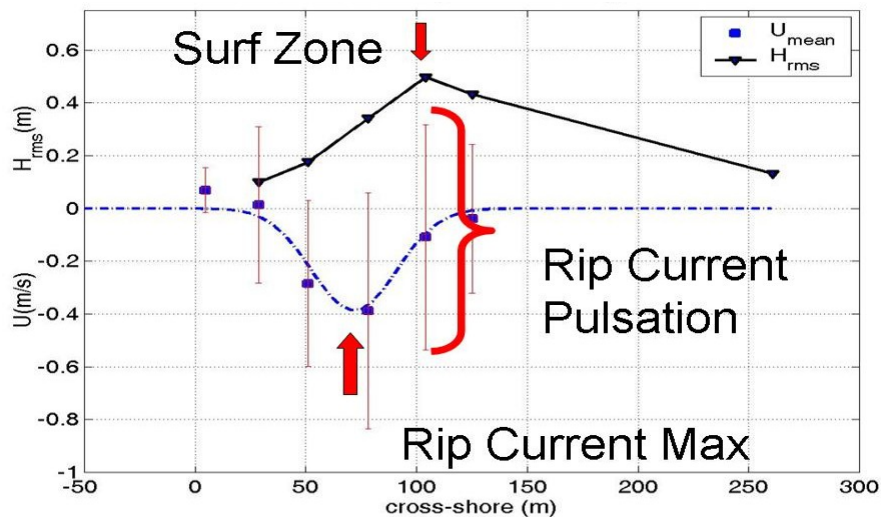


Figure 1. Rip current velocities, U , measured at approximate mid-depth in the cross-shore during NCEX. The maximum rip current velocity occurs inside the surf zone (extent of surf zone is defined where the rms wave height, H_{rms} is a maximum). The mean rip current velocity decays rapidly outside the surf zone. Pulsations of the rip current are due to infragravity waves (wave periods 20 – 250 seconds) and very-low-frequency vorticity oscillations (periods 4 – 20 minutes).



Figure 2. *The NPS bottom boundary layer frame at low tide during NCEX. From left to right are located the scanned altimeter, BCDV velocity and sediment profiler, reference EM current sensor, ADV, and bed imaging camera, all of which were submerged through the high half of each tidal cycle. The instruments are approximately 1m above the bed.*

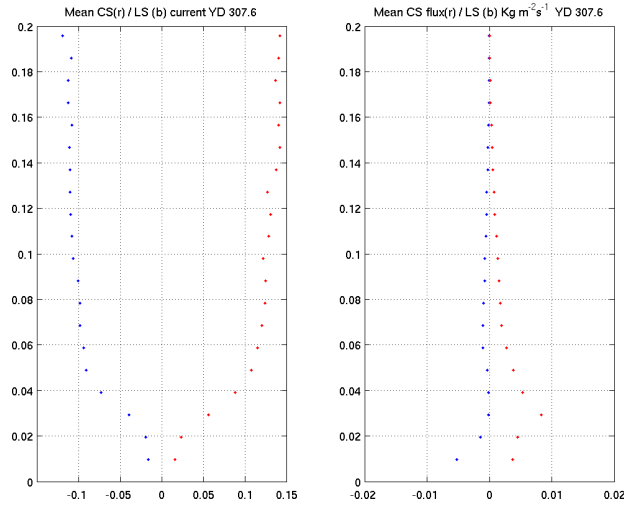


Figure 3. *Left panel: Mean (one-hour) bottom boundary layer current profile measured by the BCDV. The right panel shows the corresponding sediment flux profile estimated from sediment concentrations based on the calibrated backscatter intensity measured by the BCDV.*

PUBLICATIONS

MacMahan, J.H., E.B. Thornton, T.P. Stanton and A.J.H.M. Reniers, 2005a, RIPEX-Observations of a rip current system, *Marine Geology*, 218 (1-4), 113-134.

Gallagher, E, S. Elgar, R.T. Guza and E.B. Thornton, 2005, Estimating nearshore seafloor roughness with altimeters, *Marine Geology*, 216 (1-2), 51-57.

Reniers, A.J.H.M., E.B. Thornton, T.P. Stanton and J.A. Roelvink, 2004, Vertical flow structure during Sandy Duck: Observations and modeling, *Coastal Eng.* (51) 237-260.

MacMahan, J., A.J.H.M. Reniers, E.B. Thornton and T.P. Stanton, 2004a, Surf zone eddies coupled with rip current morphology, *J. Geophys. Res.*, 109, C07004, doi:10.1029/2003JC002083.

MacMahan, J., A.J.H.M. Reniers, E.B. Thornton and T.P. Stanton, 2004b, Infragravity rip-current pulsations, *J. Geophys. Res.*, 109, C01033, doi:10.1029/2003JC002068.

Reniers, A.J.H.M., E.B. Thornton and J.A. Roelvink, 2004, Morphodynamic modeling of an embayed beach under wave-group forcing, *J. Geophys. Res.*, 109, C01030, doi:10.1029/2002JC001586.

Thornton, E.B., A.H. Sallenger, J. Conforto Sesto, L. A. Egley, T. McGee, and A.R. Parsons, 2005, Sand Mining Impacts on Long-Term Dune Erosion in Southern Monterey Bay, accepted in *Marine Geology*.

Holman, R.A., G. Symonds, E.B Thornton and R. Ranasinghe, 2005, Rip Spacing and Persistence on an Embayed Beach, accepted *J. Geophys. Res.*

Reniers, A.J.H.M., J. MacMahan, J. E.B. Thornton, and T.P. Stanton, 2005a, Modeling Infragravity Motions on a Rip-Channel Beach, accepted, *J. Coastal Engineering*.

MacMahan, J, E.B. Thornton and A.J.H.M. Reniers, 2005b, Rip Current Review, *J. Coastal Engineering*, accepted.

Gallagher, E, R. Holman and E.B. Thornton, 2005, Evolution of the bed envelope, accepted *Marine Geology*.

Reniers, A.J.H.M., J.H. MacMahan, E.B. Thornton, and T.P. Stanton, 2005b, Modeling of very low frequency motions during RIPEX, submitted to *J. Geophys. Res.*

CONFERENCE PRESENTATIONS

Thornton, E.B, A.H. Sallenger Jr., J. MacMahan, A. Reniers and, G. Symonds, Rip-Currents, Cuspate Shorelines and Eroding Dunes, Sediments '05 Conference, Barcleno, Spain, 2005.

Thornton, E.B., J. MacMahan, A.J.H.M. Reniers, T.P. Stanton, Rip-currents and Large beach Cusps. *EOS Transactions*, Ocean Sciences meeting, Portland Oregon, *EOS Transactions* January 2004.

MacMahan, J. H., A. J. H. M. Reniers, E. B. Thornton, T. P. Stanton, G. Symonds, NCEX: Torrey Pines rip currents, *EOS Transactions*, Ocean Sciences meeting, Portland Oregon, *EOS Transactions* January 2004.

Stanton, T. P., E. B. Thornton, 2004. The Influence of Breaking Waves on the Bottom Boundary Layer Within the Surf Zone. Ocean Sciences meeting, Portland Oregon, *EOS Transactions* January 2004.

MacMahan, J., Field observations of rip currents, Sea Grant and NOAA Workshop Addressing predictive capabilities of rip currents, Jacksonville, FL, 2004.

Thornton E.B., G. Symonds, A.H. Sallenger Jr., A. Reniers and J. MacMahan, Rip-Currents, Cuspate Shorelines and Eroding Dunes, 29th International Conference on Coastal Engineering, ASCE, 2004.

Thieke, R.J., J. Engle, J. MacMahan, M. Schrader, E. Gutierrez, Observed wave conditions during rip current "outbreaks" in Florida, 29th International Conference on Coastal Engineering, ASCE, 2004.

Callaghan D., T. Baldock, P. Nielsen, D. Hanes, K. Haas, J. MacMahan, Pulsing and circulation in rip current system, 29th International Conference on Coastal Engineering, ASCE, 2004.

MacMahan, J., A.J.H.M Reniers, E.B. Thornton, T.P. Stanton, NCEX - Migrating rip currents, 29th International Conference on Coastal Engineering, ASCE, 2004.

Orzech, M.D., E. Thornton, T. Stanton, J. MacMahan, Evolution of rip and beach cusp bathymetry, *EOS Trans.*, AGU, 2004.

Thornton, E. J. MacMahan, A. Reniers, and T. Stanton, Rip currents and large beach cusps, *EOS Trans.*, AGU, 2004.

Reniers, A., J. MacMahan, E. Thornton, and T. Stanton, Canyon effects on Nearshore Infragravity Waves During NCEX, *EOS Trans.*, AGU, 2004.

THESIS DIRECTED

Woods, John, Rip current/cuspate shoreline interactions in Southern Monterey Bay, M.S. Thesis, Naval Postgraduate School, September 2005.

McWilliams, Brandon, Cuspate Shoreline Response to Rip Current Systems, M.S. Thesis, Naval Postgraduate School, June 2005.

M. E. Sweeny, Breaking Wave Turbulence in the Surf Zone, MS thesis, Naval Postgraduate School, June, 2005.

Yemm, Sean, Field Observation of Setup, MS Thesis, Naval Postgraduate School, March 2004.